Model For Generation Planning In An Electric Power System

Anton Causevski*, Tome Bosevski**

*Faculty of Electrical Engineering - Skopje, Macedonia, caus@etf.ukim.edu.mk
**Macedonian Academy of Sciences and Arts, Skopje, Macedonia

Abstract - This paper presents the methodology for power generation planning in a complex electric power system. The model objective is to find an optimal power supply that meets the hourly electricity demand, and takes into account the operating conditions of the power generating stations. The model and the developed computer program are applied to the Macedonian Power System to provide a realistic application example, and to demonstrate the role and importance of the hydro power stations in the Macedonian Power Supply System.

1. THE MODEL FOR GENERATION PLANNING

This paper outlines the improvements of the original mathematical model developed by Bosevski and Causevski [1, 2, 3]. The improved model includes energy balancing, and power balancing in each time interval for each thermal power plant, as well as water inventory balancing for the hydro power plants. The optimisation procedure can be applied to different time intervals in each specific application. The calculations can be performed on time intervals wider than 24 hours, such as: on monthly, weekly and daily basis. In addition, the calculations can be performed with time subintervals down to 1 hour, or less, depending on the available data.

The total power load is defined as average value in a desired subinterval:

$$P_{tot} = \frac{W(\Delta t)}{\sum_{t_i=1}^{t_n} t_i} = \frac{\sum_{t_i=1}^{t_n} P(t_i)\cdot t_i}{\Delta t}, \qquad (1)$$

where $\sum_{t_i=1}^{t_n} t_i = \Delta t$

If the Generation System consists of:

K –Thermal Power Plants

N – Connected Systems (Total Load)

V – Connected Systems (Variable Load)

M- Hydro Power Plants

The optimization function is minimizing the electricity generation expenses as following:

$$\sum_{k=1}^{K}\sum_{t=1}^{T}\left(K_k(P_{k,t}) + B_k\cdot(P_{k,t}-\overline{P_{k,Tkp}})^2\right)\cdot\Delta t +$$
$$\sum_{n=1}^{N}\sum_{t=1}^{T}\left(K_n(P_{n,t}) + A_n\cdot(P_{n,t}-\overline{P_{n,Tnp}})^2\right)\cdot\Delta t + \qquad (2)$$
$$\sum_{v=1}^{V}\sum_{t=1}^{T}\left(K_v(P_{v,t}) + C_v\cdot(P_{v,t}-\overline{P_{v,Tvp}})^2\right)\cdot\Delta t \rightarrow \min$$

where:

$$K_i(P_{i,t}) = P_{i,t}\cdot\left(A + B\cdot P_{i,t} + C\cdot P_{i,t}^{\ 2}\right) \quad i = k,n,v \qquad (3)$$

The following conditions are included in the model:

$$\sum_{k=1}^{K} P_{k,t} + \sum_{n=1}^{N} P_{n,t} + \sum_{m=1}^{M} P_{m,t} = P_{l,t}$$ total load:

$$\sum_{m=1}^{M_a} P_{m,t} + \sum_{v=1}^{V} P_{v,t} = k_v \cdot P_{w,t}$$ variable load

$$\sum_{t=1}^{T} P_{k,t}\cdot\Delta t = W_k$$ TPP's generation

The model offers a high degree of flexibility, and can be applied in different situations because the optimisation period can be subdivided in as small subintervals depends on the examination and input available data. In order to achieve this flexibility, model improvements were introduced with respect to the terms covering the hydro power plants and the thermal power plants energy change representation.

Tab1.*Example of some calculation with the model*

Interval Duration	*No. of Intervals*	*Additional Water Balance*	*Matrix Dimension (N)*	*No. of Matrix Elements (N x N)*	*nonzero elements in the Matrix*		*Execution Time*
						%	*s*
Intervals > DAY							
month	12		22	484	250	51,65	<1
week	52		62	3,844	1.05	27,31	<1
day	364		374	139,876	7.29	5,21	1
Intervals < DAY							
6 i 18 h	728	182+364	1284	1,648,656	18,028	**1,09**	8
8 h	1092	52+364	1518	2,304,324	25,158	**1,09**	10
6 h	1456	58+364	1888	3,564,544	33,928	**0,95**	15
4 h	2184	364+364	2922	8,538,084	51,698	**0,60**	20
3 h	2912	58+364	3344	11,182,336	68,864	**0,61**	25
2 h	4368	364+364	5106	26,071,236	105,570	**0,40**	50
1 h	8736	364+364	9474	89,756,676	210,102	**0,23**	150

Tab.1 gives overview of some calculations for the Macedonian Electric Generation System depend on different intervals.

2. CONTROL OF THE HYDRO POWER PLANTS OPERATION

As the inflow of energy resulting from water inflow in an accumulation is expressed as

$$W_{m,Tmw}^{dotek} = \sum_{\Delta t\in Tmw} P_{m,t}^{dotek}\cdot\Delta t \qquad (4)$$

and the generated energy from water outflow is expressed as

$$W_{m,Tmw}^{istek} = \sum_{\Delta t \in Tmw} P_{m,t} \cdot \Delta t \qquad (5)$$

than the expression:

$$S_m \cdot \sum_{t=1}^{T} \left(\frac{W_{m,Tmw}^{istek} - W_{m,Tmw}^{dotek}}{\sum_{\Delta t \in Tmw} \Delta t} \right)^2 \cdot \Delta t \qquad (6)$$

represents an additional condition that needs to be satisfied to optimise the generated power of a Hydro Power Plant (HPP) “m”, as a result from water inflow during the period T_{MW} . This is particularly important for regulating the discharge as well as water storage level in the reservoir.

The inflow water volume $V_{m,Tmj}^{dotek}$ in the HPP "m" reservoir during the period T_{mj} can be expressed using the inflow volumetric flow rate $Q_{m,t}^{dotek}$:

(7)

The outflow water volume $V_{m,Tmj}^{istek}$ in the HPP's "m" reservoir during the period T_{mj} can be expressed using the discharge flow rate $Q_{m,t}^{istek}$:

$$V_{m,Tmj}^{istek} = \sum_{\Delta t \in Tmj} Q_{m,t}^{istek} \left(\frac{P_{m,t}}{H_{m,t}}\right) \cdot \Delta t \qquad (8)$$

The control of the water outflow (HPP power generation control) during the period T_{MJ} is achieved through the following term:

$$\sum_{Tmj=1}^{Tmv} \mu_{mj} \cdot \left(V_{m,Tmj}^{istek} - V_{m,Tmj}^{dotek} \right) \qquad (9)$$

This is particularly important for the reservoirs with small water inventories compared to the water inflow during the analysed period. This model feature helps to provide an appropriate treatment that is consistent with the reservoir water inventories (some reservoirs can be treated on yearly basis, whereas other reservoirs on seasonal, monthly, weekly, or daily basis).

3. MACEDONIAN ELECTRIC POWER SYSTEM

The model is applied to the Power Generation System of Macedonia to provide a realistic application example, and to demonstrate the role and importance of the hydro power stations in the Macedonian Power Supply System. The Macedonian Power Generation System consists of (Table 2)

a) 4 coal-fired thermal power plants (Bitola 1,2,3, each with 225 MW installed electric power, and Oslomej, with 120 MW installed electric power),
b) one oil fired thermal power plant (Negotino, with 210 MW installed electric power), and
c) 9 hydro power plants, 5 with storage water reservoirs, and 4 are direct river flow plants.

Tab2.*Overview of the general performances for storage HPP*

Storage HPP	Water Storage ($10^6 m^3$)	Gross Head (m)	Installed capacity (N x m^3/s)	Ave. yearly inflow (m^3/s)
Vrutok	277	572	4 x 8	9,90
Kozjak	260	102	2 x 50	21,20
Tikves	272	100	4 x 30	27,40
Globocica	228	101	2 x 27.4	28,50
Spilje	212	95	3x36	47,50

The electricity productions of the thermal power plants in Macedonian Power Generation System are set based on their production capability and fuel supply availability.

4. THE ROLE OF HYDRO POWER PLANTS

The results presented in this paper by an example of electricity generation planning in the Macedonian Power System, are aimed at demonstrating the capabilities of the improved model.

The analyzed period is 5 years (1996-2000), during which the energy demand is presented with 3654 points, and each day is divided in 2 intervals (8 & 16 hours on Fig.1).

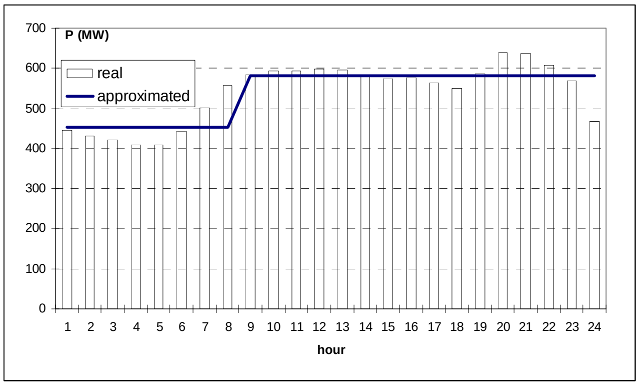

Fig. 1. Divided day into 2 intervals according (1)

The power generation in all nine hydro and five thermal power plants in the Macedonian Power Generation System are optimized, and the estimated energy demand is 40000 GWh in total during the 5-year period.

HPP Vrutok (high gross head) and HPP Globocica (large water inflow based on installed capacity), both with relatively large water inventory, can be used for saving water inventory during the 5year period. The other HPPs (Tikves Kozjak & Spilje) have a gross head of about 100(m), and water inventory capacity of over 200 mill m^3. These HPPs have a large water level to water inventory ratio, e.g. their power generation is sensitive to the reservoir water level, and these HPPs are not to be operated with large variation of the reservoir water level. Therefore, these HPPs need to use the water inflow over each year.

5. DISCUSSION OF RESULTS

Figure 1, 2 and 3 present the inflow energy, generated energy and accumulated energy, respectively, for the best 5 years (1979-1983) in terms of water inflow.

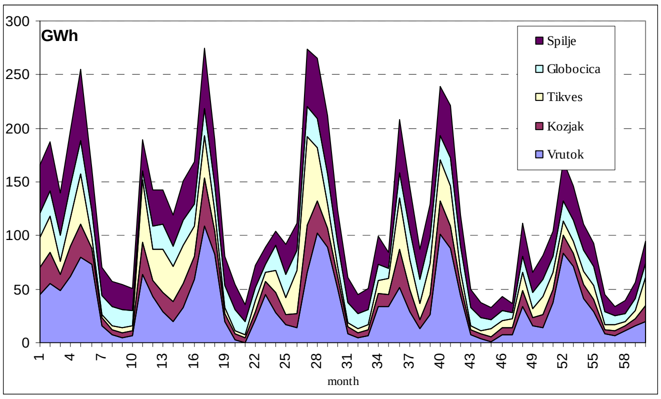

Fig. 2. Inflow energy in the reservoirs for wet period

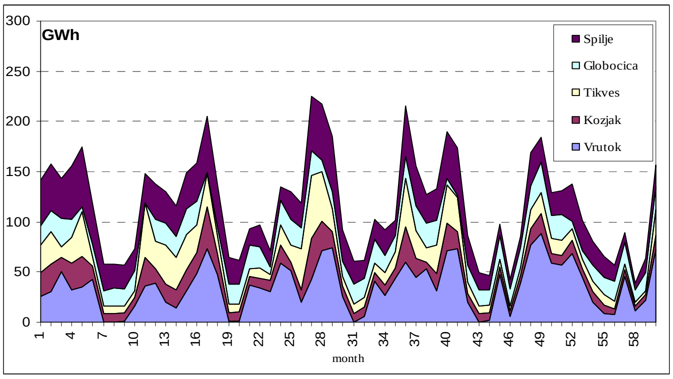

Fig. 3. Generated energy of the HPPs for wet period

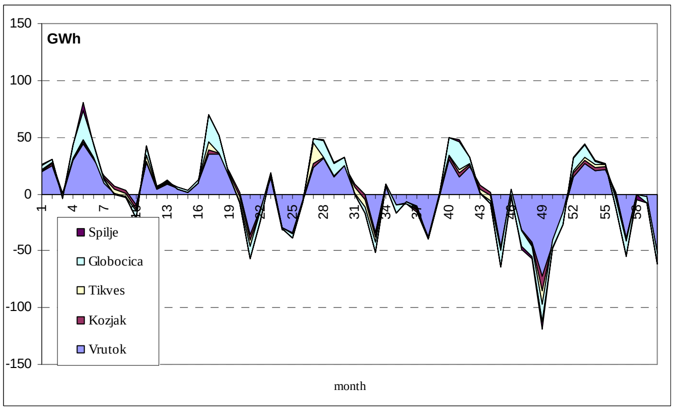

Fig. 4. Accumulated energy of the HPPs for wet period

Fig.5, Fig.6 and Fig.7 present the inflow energy, generated energy and accumulated energy respectively, for the average hydrology period of 5 years (1973-1977).

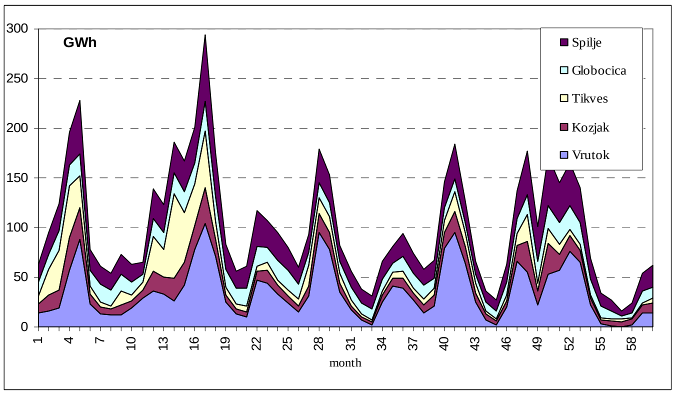

Fig. 5. Inflow energy in the reservoirs for average period

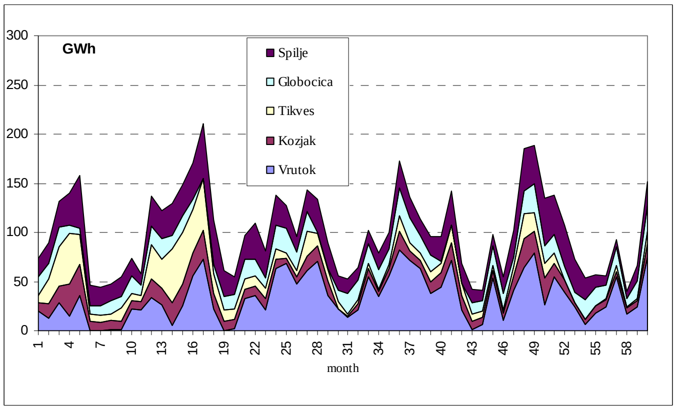

Fig. 6. Generated energy of the HPPs for average period

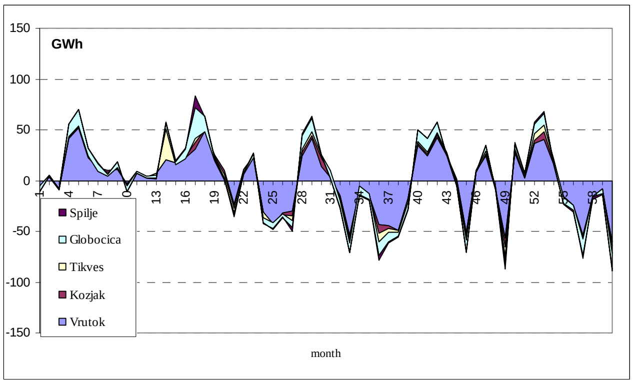

Fig. 7. Accumulated energy of the HPPs for average period

Fig.8, Fig.9 and Fig.10 present the inflow energy, generated energy and accumulated energy respectively, for the dry hydrology period of 5 years (1990-1994).

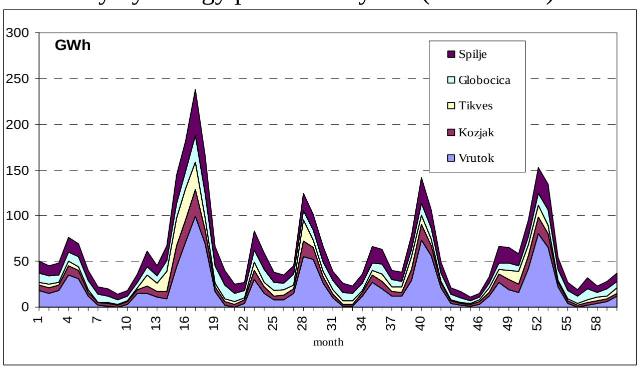

Fig. 8. Inflow energy in the reservoirs for dry period

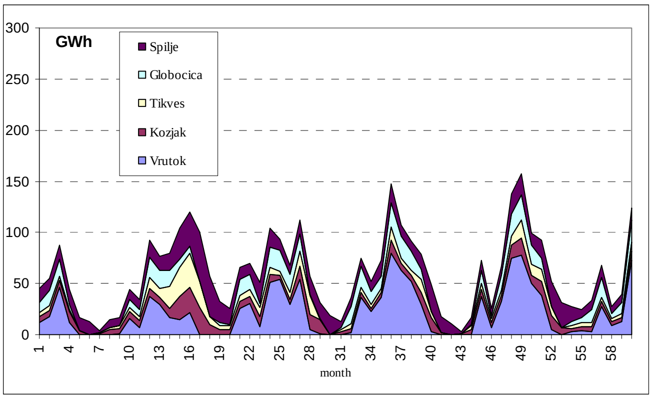

Fig. 9. Generated energy of the HPPs for wet period

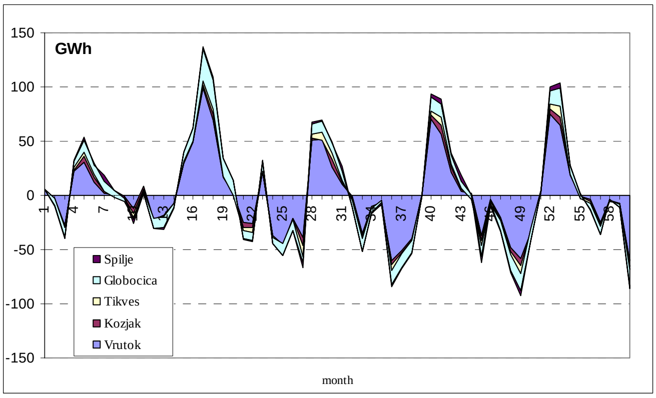

Fig. 10. Accumulated energy of the HPPs for average period

These figures demonstrate the role of the HPPs in different hydrology conditions with respect to the generated energy and accumulated water inventory. Obviously, saving water in the HPP reservoirs is greater in dry (Fig.10) than in average (Fig.7) or wet (Fig.4) periods. These results are obtained for the three hydrology periods with the same variations of the water reservoir levels, as follows: Mavrovo (HPP Vrutok) of about 15 (m), Ohrid lake (HPP Globocica) of 0,65 (m), and others reservoirs of about 10 (m).

6. CONCLUSION

The presented example of optimised planning of power generation in the Macedonian Power Generation System demonstrates the model capability in identifying the appropriate operating mode of the hydro power plants in the system. HPP Vrutok and Globocica have relatively large reservoir capabilities (can save water during the 5-year period.

The other HPPs, Kozjak, Tikves and Spilje, can save the water only over one-year period. Their contributions in the accumulated energy longer than 1 year are not significant, but on the other hand, the variation of the water level over 10 (m) will lead to significant energy loses.

The model capabilities can be used to ensure an optimised energy generation in a small power generation system, with an adequate energy supply that meets the projected energy demand each time interval.

The following points can be considered by using the presented model, aimed at improving the operation of the power generation system:

- Analyze hydrology influence on electricity generation of the HPPs,
- Define power plant operation to meet the electricity demand in a given time interval.
- Analyze operation of a series of linked HPPs, according to their hydro & technical parameters.
- Analyze pumping and generating operation using reversible HPPs,
- Determine the reservoir status of the existing storage HPP (water storage level during the period)
- Plan yearly operation, including outages of the thermal power plants, especially for the oil-fired plants, by taking into account the fuel price.
- Analyze the needs for increasing the installed capacity for some existing HPPs.
- Define the installed capacity and the operating role of the new HPPs & TPPs in the Power System.

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